Review of "The role of equatorial waves in triggering weather extremes in the Maritime Continent", Ph.D. Dissertation by Beata Latos, Institute of Geophysics Polish Academy of Sciences

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The dissertation research by Beata Latos is principally contained in three publications in the refereed literature. The papers are preceded by a summary discussion of the authors' findings, which serves as a guide for understanding and interpreting those studies as well as providing an integrating theme to the dissertation. Briefly stated, the theme is that through case and long-term studies, the roles of subseasonal disturbances (MJO, Kelvin waves, equatorial Rossby waves) in extreme rainfall over the Maritime Continent (MC) have been elucidated to the benefit of weather prediction in the region.

Comments on Introductory Section (prior to the papers)

This section is well written, and the research problem is well stated. A few minor comments:

1. P. 8: The discussion centers around multiscale phenomena impacting rainfall over the Maritime Continent (MJO, Kelvin waves, equatorial Rossby waves). However, the discussion would not be complete without at least mentioning the impacts of ENSO and the IOD on rainfall in this region. Long-term studies need to be carried out on time scales of a decade or longer that capture the various phases of ENSO/IOD to determine how well the results can be generalized.
2. P. 8: The term CERW is introduced without being defined.
3. P. 9: The term "predictability barrier" is introduced but not defined. My understanding is MC predictability barrier refers to the inability of models to accurately simulate the passage of the MJO over the MC.
4. Given that there are large topographic barriers and land/sea contrasts over the MC, comments could be added as to whether these factors play a role in some flooding events beyond the effects of subseasonal atmospheric phenomena.

Baranowski et al. (2020): Social-media and newspaper reports reveal large-scale meteorological drivers of floods on Sumatra, Baranowski et al., *Nature Communications*. Beata Latos contribution to this study: 10%.

This paper reports on the findings of a study of the principal mechanisms for extreme rainfall in Sumatra. In an investigation of over 400 heavy rainfall events during 2014-2018, it was found that convectively coupled Kelvin waves (CCKWs) were implicated in some way in most of the storms, suggesting that forecast models capable of tracking CCKWs over the Indian Ocean can improve prediction of extreme rainfall over Sumatra. While the MJO was also found to influence the occurrence of heavy rainfall, the direct linkage to CCKW passage was far greater. It

was found that CCKWs were associated with 90% of all floods in Sumatra and solely responsible for nearly 30%. A unique aspect of this study is quantifying the role of CCKWs in heavy rainfall in the Maritime Continent. Another unique aspect is the use of social media (Twitter along with local newspapers) in assisting the identification of extreme rainfall events. I am not aware of any other study that has made use of social media in this way.

The findings of this paper are important and well presented. The paper already has 32 citations on Google Scholar. With regard to the representativeness of the results, how might they be influenced by ENSO and the IOD? For example, 2015-16 was a very strong El Niño period, during which precipitation over the MC is typically suppressed. In Baranowski et al. (2020) a time series for 2017 is presented. It would be interesting to know what the time series looked like for the 2015-16 El Niño period. A similar question could be raised regarding the phases of the IOD. For example, there was a strong negative phase of the IOD in 2016 (warm water in the eastern Indian Ocean), which is usually found to be associated with above-normal rainfall over Java, Indonesia.

Latos et al. (2021): Equatorial waves triggering extreme rainfall and floods in southwest Sulawesi, Indonesia. *Monthly Weather Review*, **149**, pp.1381-1401. Beata Latos contributed 80% to this publication.

This paper reports on the results of both a case study of extreme rainfall in southwest Sulawesi on 22 January 2019 and a long-term study of the role of equatorially trapped waves on extreme rainfall in this region for the period 1998-2019. The results show that while the MJO active phase passage over the region enhances the likelihood of heavy rainfall, CCKWs and CCERWs further increase the probability of extreme rainfall.

The study employs an impressive array of observations (satellite, radar, surface rain gauge, sounding, reanalysis data) and analysis tools (equatorial wave filtering, MCS tracking, EOFs). The authors have effectively integrated the data and analysis tools to make a strong case for the important roles of CCKWs and CCERWs in southwestern Sulawesi. The paper is well written and does an excellent job of relating the work to other published studies.

Specific comments:

1. Figs. 2 and 12 and related discussion of MCSs: It is argued that a single MCS (Abstract) that developed in the Java Sea is causal factor for the extreme rainfall for the 22 January 2019 flood case. A tracking algorithm that uses both IR brightness temperatures and GPM IMERG rainfall to identify precipitation features having specified area and rain rate thresholds and lasting longer than 5 hours and label them as MCSs. A link to an animation of MCS-related rainfall is provided. While it is suggested that the heavy rainfall was related to an MCS, the animation indicates multiple rain areas that jump around from place to place upstream of the flood region near Makassar. The rain map in Fig. 2 indicates the heaviest rainfall occurred over the slopes of the mountainous terrain and seemingly unlinked to the heavy MCS rainfall offshore. If a single MCS was

responsible for the flooding rains, it would have been helpful to have shown a satellite and/or radar image of the system at its mature stage. While MCSs over the Java Sea may have become more prevalent during the heavy rainfall period, it is suggested from the sounding time series in Fig. 9 that the heavy rainfall peaking on the 22nd was directly linked to the rapid increase in westerlies at that time impinging on the mountain slopes east of Makassar. There is also a rapid increase in low-level convergence at that time.

2. Fig. 3, rainfall time series: On p. 1395 it is stated that in this flooding case the diurnal cycle did not play a major role in the heavy rainfall. The time series in Fig. 3 shows a peak in rainfall at 0000 UTC (0800 L) both on the 22nd and 23rd. While this early-morning timing of the heaviest rainfall argues against any role of sea breezes, could this timing suggest a possible role of land breezes enhancing rainfall near the base of the mountain range such as occurs at the base of the Himalayas where there is a nocturnal rainfall maximum due to convergence of the nighttime drainage flow with the southwest monsoon flow (e.g., Barros and Lang 2003). While this may not have happened, the possibility could at least be mentioned.
3. P. 1388: At the bottom of the page, it is stated that cyclonic vorticity provides an environment favorable for the development of MCSs. The next sentence refers to the MJO and CCKW, as well as CCERW, but it is not clear what the reader is supposed to refer to in connection with cyclonic vorticity.
4. Pp. 1389-1390: With regard to the section on "Other causes of flood", there is no mention of the diurnal cycle (which may or may not play a role) or topographic effects or land/sea breezes. From Fig. 2, steep topography appears to have played an important role in the heavy rainfall.
5. P. 1394: How does midlevel vorticity enhance the rainfall? Does it strengthen the MCSs or is there some other effect?
6. P. 1397: It is stated that cross-equatorial cold surges are not totally distinct features from CCEWs. Since South China Sea cold surges are initiated by cold-air outbreaks at midlatitudes over China, how are they connected to equatorial waves?
7. With respect to the long-term study, how do the results vary in connection with ENSO and the IOD? For example, rainfall is suppressed over the MC during an El Niño, so the relationship of extreme rainfall to equatorial waves could be impacted.

Latos et al. (2023): The role of tropical waves in the genesis of Tropical Cyclone Seroja in the Maritime Continent. *Nature Communications*, **14**, p.856. Author contributed 80% to this publication.

This paper deals with the rare tropical cyclone Seroja that developed in April 2021 relatively close to the equator near Timor Island. The authors trace its initiation to a synergistic interaction of several equatorial disturbances: the passage of an MJO over the Maritime Continent, two convectively coupled Kelvin waves, and a convectively coupled equatorial Rossby wave. Some of the observational data sources and analysis techniques used in the previous Latos et al. (2021) study of the flooding event in Makassar were used in this study. In this regard, the study represents an extension of past work to a new area of extreme weather research.

The study presents a rather convincing argument for the fortuitous coupling of a number of equatorial disturbances leading to the formation of Seroja. This TC caused extreme flooding to Timor and surrounding islands, so its development is worthy of study as is the fact that it occurred so close to the equator. The analysis of the vorticity budget for this case using ERA5 data quantifies the impact of the second KW on intensification of Seroja, which puts the conjectures based on the study on fairly firm grounds. The paper is well written with a lot of material concentrated in a relatively short space. Perhaps that is because there is a size limit for the journal's articles.

Specific comments:

1. CCKW#2: Figure 6 shows CCKW #2 emanating from just south of 10°S. This is quite far off the equator to be considered a KW. Are you arguing that the *dynamic equator* at this time is around 10 degrees south of the actual equator? There is a KW feature that shows up in Figs. 4a and 6 that is along the equator and moves across central Sumatra, but that is not the feature labeled CCKW#2 in Fig. 6. CCKW#2 in Fig. 6 does have a surge of westerlies accompanying the precipitation maximum, so this aspect does resemble a Kelvin wave. The Fig. 4b Hovmöller shows a rather discontinuous KW structure connected with KW#2, not nearly as prominent as the KW pattern center nearer the equator.
2. Figs. 2 and 3: The pre-Seroja box is centered near 4°S but the CCERW track in Fig. 3 is south of 10°S. Figure 2b shows a vorticity center track starting around 5S. It is not clear when this track began and whether the initial disturbance center was related to the CCERW. Unfortunately, Fig. 2b is never discussed in the paper. Each figure that is presented should at least receive some mention in the text. The starting time for the vortex track in Fig. 2b is not indicated so it is not easy to relate the initiation of this feature to the CCERW under discussion.
3. Fig. 9: This figure is a bit confusing.
    a. The figure caption doesn't explain that the arrows refer to the direction of the flow. I initially thought that the curved arrows represented flow in the meridional direction, but after further thought, they are intended to represent flow in the vertical plane.
    b. KW#2 in the second panel starts on the equator, which makes sense, but then it shows up near 10°S in the third panel. This might make sense if the argument is made that the Kelvin wave is deflected to the south of Sumatra. However, Fig. 6 clearly shows this Kelvin wave entering the region near 10°S.

<u>Summary remarks and recommendation</u>

The dissertation consists primarily of three peer-reviewed publications, the latter two (Latos et al. 2021 and 2023) representing most of the candidate's research. An exhaustive data collection and analysis effort was carried out in connection with the Sulawesi floods as reported

in Latos et al. (2021). Many of the datasets and analysis procedures developed for both the Makassar flood and the longer-term investigation were subsequently applied to the study of the formation of April 2021 TC Seroja (Latos et al. 2023). In addition to the three publications, there is a brief introductory section that presents an overview and summary of the papers. As a result of the peer-review process, the publications are very good shape from the standpoint of their technical content and readability.

Latos et al. (2021) and Latos et al. (2023) are comprehensive observational studies of extreme weather systems causing damaging floods in the MC. In terms of the scope of the data acquired and processed, and the analysis procedures used, these studies represent substantial undertakings. While there are other studies that the candidate cites related to extreme rainfall and floods in the MC, it appears that in many regards this investigation is unique and far more comprehensive than the previous works, which makes it an important study. The papers provide rather convincing documentation and explanation of the roles of the MJO and convectively coupled equatorial waves in extreme rainfall in the cases studied.

A brief summary of several comments and questions related to the papers is as follows: Latos et al. (2021) needs clarification on the specific roles of MCSs in the Makassar flood, the impacts of topography, the possible role of the diurnal cycle and sea/land breezes, and the effects of ENSO and the IOD on the long-term results; and Latos et al. (2023) needs clarification on the nature of KW#2 that begins so far off the equator and the interpretations of Figs. 2, 3, and 9.

My overall conclusion is that Ms. Beata Latos has carried out important research that meets the expectations for a PhD dissertation. It advances understanding of the role of equatorial trapped disturbances in extreme rainfall in the MC, which clearly has the potential to improve operational forecasting in the region. I recommend that Ms. Beata Latos be admitted to further stages of the dissertation process including the defense of the doctoral dissertation publicly.

I also recommend that the dissertation be considered for the status of distinction. This recommendation is based on both the impact and nature of the research. According to Google Scholar, Ms. Latos has been involved in a total of seven peer-reviewed journal publications since 2018, four of which are in the area of her dissertation (tropical weather systems) and three in prior research areas (water quality and glacial studies). She is senior author on two papers in each of these categories. Latos et al. (2021) has already received 14 citations, which is a noteworthy achievement for a 2021 publication. Regarding the nature of her work, it is a significant challenge to integrate multiple datasets and apply diagnostic tools to effectively tease out salient physical processes in a meaningful way. Ms. Latos has clearly demonstrated the ability to do this. These skills tend to be rare in an era where many dissertations involve analysis and interpretation of numerical modeling results, often without reference to observations.